Real-Time 3D Nautical Navigational Visualisation

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ABSTRACT

This paper presents a research project suggesting the use of real-time 3D techniques normally used in simulation environments as a navigation aid onboard ships. Based on a three-dimensional geographical database the surrounding world is presented in a "bridge-eye perspective" with navigational information such as own track, other ships in the vicinity and their tracks, water depth and radar echoes integrated in a single display. The integrated display suggested, acts as a complement to traditional electronic charts. The main objective is to lessen the cognitive load of the bridge personal and particularly the helms man in hand steering situations in high-speeds. (See fig. 1.)
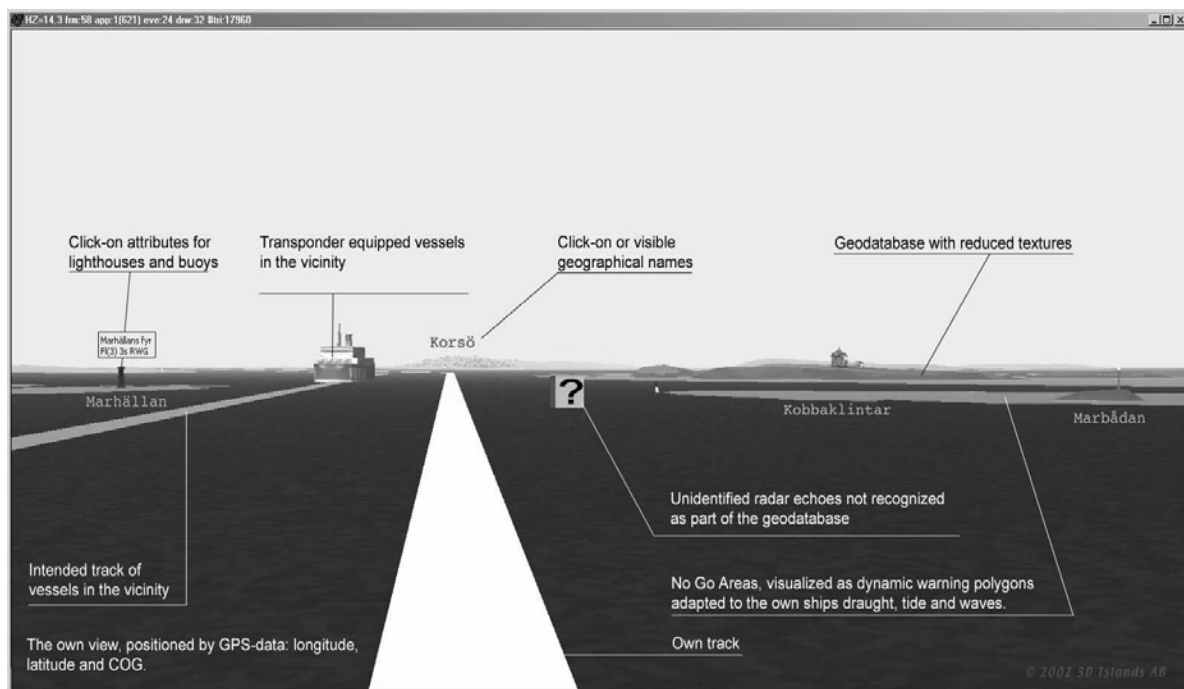
Figure 1: Navigational Information Presented from a Bridge Perspective. The screen dump shows the entrance to Mariehamn in the Åland Archipelago in the Baltic Sea, on the ferry lane between Finland and Sweden.

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1.0   INTRODUCTION

On many vessels the everyday navigational duties of an Officer of the Watch (OOW) can be peacefully undertaken with a jug of coffee in hand. But the introduction of high-speed crafts and more and more advanced navigation equipment augments rapidly the cognitive load of the OOW and shorten the time of decision-making. There is a need for systems that balance the amount of information and present the right information at the right moment in an easy to understand way.

This paper first touches on the basic cognitive and infological problem of information visualisation. It implies the need for a new theory to understand the cognition and use of new "maps" that are digitally stored, dynamic and adjusted to the user situation, displayed in 3D and merging information from several sources. The bird's-eye and bridge-eye map perspective are discussed. A general overview of the geographical database is presented and, more detailed, the procedure of representing deep-water corridors and No GO Areas.

Concluding the paper is some items of future research.

The aim of this research project is to find ways to lessen the cognitive load of the navigator by presenting all crucial navigational information in one integrated display. The integrated view shall in a glance answer questions like: Am I on the right track? What is the intention of the approaching ship? In case of an evasive manoeuvre, where is there enough water under the keel for my vessel?

To prevent mistakes in stressed situation we are suggesting the use of a coning display using a bridge-eye perspective from a three-dimensional chart instead of the normal cartographic bird's-eye perspective.

2.0   THEORETICAL BACKGROUND

Two different concepts form the theoretical basis of this project: In regards to cognition there is the notion of Spatial Mental Models, and in regards to infological and datalogical questions regarding information systems there is the Infomatic Equation. But before we reach to that we need to do a definition.

2.1   Visualisation/Visualization

The word visualization in the title of this paper may need some further clarification. The word is often in British and Australian English spelled with an "s": visualisation. In Oxford English Dictionary defines the word as "the power or process of forming a mental picture or vision of something not actually present to the sight; a picture thus formed." But the Free On-Line Dictionary of Computing has a different definition: "Making a visible presentation of numerical data, particularly a graphical one. This might include anything from a simple X-Y graph of one dependent variable against one independent variable to a virtual reality which allows you to fly around the data."

What we see here is the confusion between a general use of the word, as something going on inside the human mind, and the computer graphics-people's use of the word, as something going on in a computer and on its display.

Chipman [2] cites a definition of visualization as "…transformations that convert data into a format amenable to understanding by the human perceptual system, while maintaining data integrity," [7].

In the field of Visualization in Scientific Computing (ViSC) Visvalingam 1994 [16] tried to make a distinction based on the spelling of the word: Visualisation, with an "s" he defined as the mental process and product and visualization with a "z" as the computational process resulting in a visual mage on a computer screen.

This distinction has not had much success; We will however use it in this paper. Often in literature the words visualisation/visualization is used without this distinction and one has to be observant on what exactly is meant.

2.2   Spatial Mental Models

There is a notion that people's mental representations of environments are embodied in so-called *cognitive maps*, cognitive mental constructs that, like real maps, can be mentally inspected. As maps they are presumed to be coherent wholes that reflect spatial as well as metric relations among elements.

Stanford cognitive psychologist Barbara Tversky [15] questions the *map* expression, pointing out the many systematic and other errors in people's memory for environments. Instead, she says, people acquirer disparate pieces of knowledge about environments. Pieces like recollections of journeys, memories of maps, recall of verbal directions and facts, and more. Instead of *maps* she wants to call these internal representations *cognitive collages*. "[Cognitive] collages are thematic overlays of multimedia from different points of view. They lack the coherence of maps, but do contain figures, partial information, and differing perspectives," she says. But she also states:

> In other situations, especially where environments are simple or well-learned, people seem to have quite accurate mental representations of spatial layouts. On close examination, these representations capture the categorical spatial relations among elements coherently, allowing perspective-taking, reorientation, and spatial inferences.

Tversky terms these mental representations Spatial Mental Models, and remarks that although they do not preserve metric information, they do preserve coarse spatial relations coherently.

As to the structure, Tversky finds that:

> these spatial mental models are akin to an architect's model or a structural description of an object. They have no prescribed perspective, but permit many perspectives to be taken on them. Thus, spatial mental models are more abstract than images, which are restricted to a specific point of view.

In a series of studies Tversky finds that subjects making descriptions of their spatial mental models take two different, but very specific, perspectives. Tversky calls them route and survey perspective. The essence of the route perspective is the coherent moving viewpoint changing location and orientation in relation to the frame of reference, while the essence of the survey perspective is the fixed perspective allowing for the description of the location of a landmark relative to the location of another landmark. She notes that: "descriptions used either route or survey perspectives or a combination of both. No other style of description emerged."

Could this concept be useful for constructing a navigational aid simulating the spatial mental model, and would such an instrument benefit the voyager in a better way than the prevailing aids?

Perhaps. If we can construct a navigational aid that can simulate our inner spatial mental model, allowing us to freely change perspective, from route to survey and back, to examine ahead on our intended track, in the same way as we can mentally, it will give us a chance to update, and correct the mental model, and prevent errors in the mental model to lead to accidents.

2.3   The Infologic Equation

The first Swedish professor in systems development Borje Langefors already in the end of the 1950's began forming theories for the coming era of information systems. He used the word *infology* to

complement *datology* thus putting the focus on information systems rather than data processing systems.[*] Data became information first through an interpretation process. One has to design information systems in close collaboration with the future users of the system in order to make sure that data really will provide the information wanted. [9]

The Langefors *Infologic Equation,* further developed by Backlund [1], is a basic model to calculate/evaluate the nature and complexity of data presented by different users during different situations of stress related to both information load and the present task.

The Infologic Equation is based on a distinction between information and data; between infological and datalogical work areas. The infological problem is how to define the information to be provided by the system in order to satisfy user needs while the datalogical problem is how to organize the set of data and the hardware in order to implement the information system. Four method areas in information systems development can be distinguished, where as the first two are infological and the last two datalogical areas. [10]

- Object system analysis and design

- Information analysis

- Data system architecture, and construction

- Realization, implementation, and operation

The equation defines the information, *I*, to be dependent on the data, *D*, and the recipient's prior knowledge, *S*, sometimes also called the covering structure, by the interpretation process, *i*, during the time, *t*:

$$I = i(D, S, t)$$

The recipient's prior knowledge is generally the result of the life experience of the individual, which, in turn, makes that not every individual will receive the intended information even from simple data.

The equation puts the focus on some important points in our intended visualization system: the factors going into the system and the one coming out. Langefors stresses the difference between data and information; information being what the user gets out of data. This is very similar to Visvalingam's distinction: visualisation being what the user gets from the visualization process. We might even try to rewrite the equation

Visualisation=visualization(data, pre-knowledge, time)

To be able to navigate a ship in a safe manner the level of visualisation will need to be constant, meaning a clear understanding of the ships situation in relation to other vessels and the world. With faster vessels the time factor is diminishing. To keep visualisation the same we either need to raise the skill, pre-knowledge, of the navigator, the quality of the data or the effectiveness of the visualization process.

The pre-knowledge of the navigator is of great importance. In other fields studies have shown big individual differences in what can be remembered from a circuit diagram as a function of knowledge of electronics. [2]

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[*] However, Pettersson [12] used the word infology with another meaning than Langefors. Pettersson wrote: "Infology is the science of verbo-visual presentation of information. On the basis of Man's prerequisites, infology encompasses studies of the way a verbo-visual representation should be designed in order to achieve optimum communications between sender and receiver. Some studies concentrate on the sender, others on the receiver, representation or communications process as such."

In studying visualisation we are interested in determining how what is "seen" in the display depends upon the experience and formal training of the individual viewing it. By contrasting what is seen by persons with varying degrees of knowledge, one can separate the influence of general human perceptual capacities from the influence of special knowledge. [2]

But we must also remember the effect of attention narrowing (tunnelling) that affects human beings in situations of stress. [18] Our aim should therefore not rely on increased pre-knowledge, but instead try to allow for less pre-knowledge by being as independent of prior training and as intuitive as possible.

It then remains for us to focus our attention to better data quality and a more efficient visualization process.

The map as a mediator of information serves several functions. Downs & Stea (1977) introduces a four level model 1) orientation, 2) the choice of route, 3) keeping in the right track and 4) discovery of the objective. The map could according Sivertun [13] be regarded as a special form of representation – different from the spoken language and mathematics by its non sequential structure that allows the user to integrate information from different sources and partly with different ontological background into a meaningful context. Fauconnier [6] introduces the Composition – Completion – and Elaboration chain to explain how a user mixes information from several maps. Ljungberg [11] further develops the questions about map semiotics and communication. These factors addresses parts but not all of the cognitive tasks a OOW have on the bridge. Suggestions how to integrate and visualize multidimensional data in 2D maps is also discussed in Sivertun [13]. To facilitate navigation in dynamic 3d environment is, however a much more complex task!

3.0   THE BIRD'S-EYE VIEW (SURVEY PERSPECTIVE)

On the bridge of a ship the surrounding world is watched not only by eye and senses, but also with the different kinds of instruments. More important than the out-of- window view is the radar. The radar offers a simple and reliable way to measure distances to objects and landmarks in the vicinity of the ship, both in fog and dark as well as in daylight. The chart, in paper or electronic format, is the other important mean of navigation. A navigational chart is a complicated information system allowing for computations and conversions between compass bearings and geographic locations, time and distance. "A navigation chart represents the accumulation of more observations that any one person could make in a lifetime. It is an artefact that embodies generations of experience and measurements." [8]

Both these systems are built on the principle that the world is looked upon from above. We call it a "bird's-eye" perspective but it is actually an artificial, orthogonal, perspective presuming the observer to be directly above all places at the same time. This so called bird's-eye perspective, or *survey* perspective, as Tversky calls it, is good at showing us an overview, and enabling us to conveniently measure directions and distances. But it has difficulties with representing areas with high resolution without losing the overview. The traditional chart also tells us little of the topography of the coast. For that kind of information we normally have to go to drawn or photographed coastal profiles in the pilot handbooks.

It takes a great deal of experience to map the chart picture to the real world outside the bridge window. The progress of the own ship's symbol on the radar and chart screen is usually represented in one of two different ways: Eider the own ship is still at the centre, or elsewhere, with the bow facing straight up and the world moving and turning around her (a so called "Head-up" display), or the world is still, normally with north facing up, and the symbol of the ship moving over the screen, with the world jumping into position when the symbol approaches the end of the screen (North-up and True Motion display).

Expert navigators often prefer the North-up display, and also using traditional paper charts oriented north-up. This gives them a common frame of reference when communicating with other ships or other persons.

[17] The problem with the North-up display is that when the vessel is heading south, a starboard turn results in a movement of the own ships symbol on the screen in the opposite direction. [See fig. 2.] This can be confusing for many inexperienced persons and one of the authors of this paper can reveal that this can be the case even for experienced officers, having witnessed a 20.000 ton tanker turning around night time in the German Elbe River in dense traffic. Research confirms that fewer mistakes are made when using the Head-up map. [5]
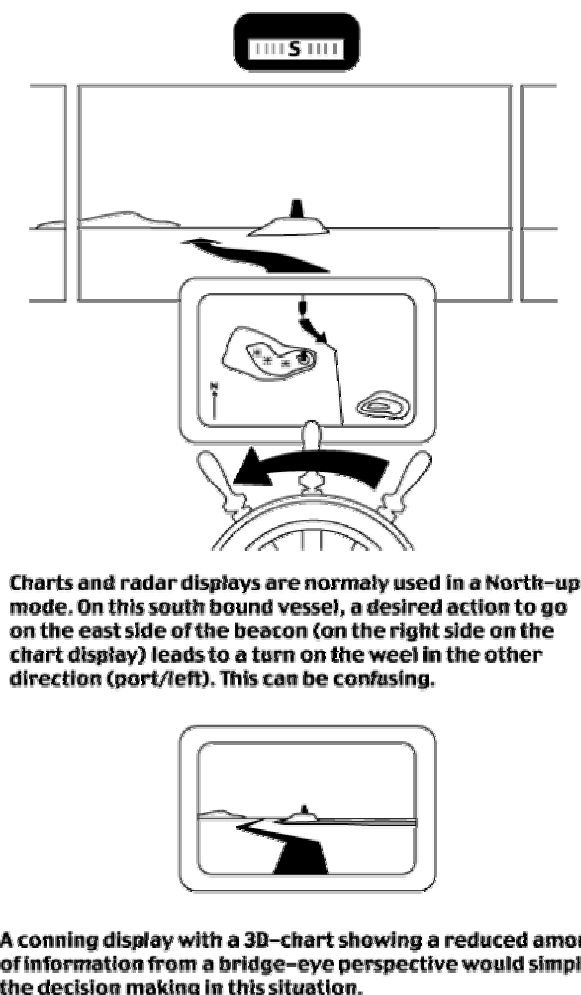
Charts and radar displays are normaly used in a North-up mode. On this south bound vessel, a desired action to go on the east side of the beacon (on the right side on the chart display) leads to a turn on the weel in the other direction (port/left). This can be confusing.

A conning display with a 3D-chart showing a reduced amout of information from a bridge-eye perspective would simplifie the decision making in this situation.

Figure 2: World Representations in "Bird's-Eye" and Bridge-Eye Perspective.

With the Head-up display the relative directions are easy to judge, but instead the moving and turning representation of the world, introduces a problem of orientation. The well-known shoreline of an island will not as easily be recognized when turned upside down.

The tradition of visualizing the world through representations from a bird's eye view goes back to the dawn of mapmaking. This said it must be recognized that understanding and using a map is not a natural skill for mankind but one that has to be trained.

4.0 THE BRIDGE (ROUTE) PERSPECTIVE

There is however another tradition of way finding at sea dating back to the old Greeks: That of the sailing direction (Greek *periplus*). Descriptive sailing directions were the principal navigation aids up until the

end of the seventeenth century. [3] A sailing direction is a written document, consisting of consecutive notes of courses to sail, notes of passage time and even drawings of landmarks from the perspective of the sailor. So while the map is an orthogonal, static representation of the world from a fixed position above, a sailing description is a temporal and dynamic representation from the point of view of the ship. [8]

Dana Tolins, [14] suggest this, the "snakes eyes perspective", in analysing geographical space. To be able to support the navigator with analytical tools, the navigation system should be able to handle data with both global and local perspectives.

Real-time 3D simulation techniques offer a mean to visualize the surroundings of a ship from the point of view of the ship. Based on a geographical database containing the topography both below and over the surface, and an "eye" positioned by GPS-data, a 3D-display from a bridge perspective is suggested as a complement to the traditional electronic chart.

Into such a system crucial navigation data can be fused, such as:

- the current tidal level

- the ships track, represented by a "road" on the surface

- dynamic depth information reduced to navigational (*go*) or not navigational (*no go*) areas for my own ship

- models representing near by vessels positioned by transponder data

- tracks representing planned routs of near by vessels, by transponder data

- geometric representations of unidentified radar echoes.

The geographical dataset mimics the real world and makes it possible to conduct daylight voyaging in dark and fog. The representation of surrounding traffic, own track, Yes and No Go Areas, simplifies navigation in high speeds and reduced visibility. Less professional navigation could be simplified to "car-driving" along a track-"road". In a cluttered archipelago and in crowded traffic situations the suggestion is, that the bridge-eye perspective offers a second chance to make a right, intuitive, decision when trained skills fail in a crisis situation. This still remains to be scientifically proven.

5.0   THE GEOGRAPHICAL DATA BASE

The system consists of a three-dimensional geographic database containing topographical information as well as attribute data. 3D-geo data bases are well established in the simulations community. Flight and driving simulators use them with different demands for resolution.

The purpose is to provide a terrain model with enough realism to make a direct comparison with the real world possible. Thus in daytime provide a frame for navigational information and in night time and in restricted visibility provide a direct mean of visual navigation.

This is not the place to go into great detail about the geo database, but we will just mention some problems that we are working with:

Above water: We have found traditional digital elevation data with a grid of 25 – 50 meter is insufficient for modelling purposes in the costal zone or in the archipelago where many dangerous rocks risk disappearing. A denser grid of maybe 2 m or less is preferable.

Above water the topographical information is collected by air photos, which are draped over the terrain model in order to provide texture.

Traditional photo grammatical methods returning the bare earth elevation is sufficient in the naked outer archipelagos of Sweden, but on the inner archipelago, the forested islands are not recognizable, lacking the trees necessary for a correct silhouette.

We are currently looking on elevation data from laser radar. This technique returns an elevation model with a grid spacing of less than a meter and accuracy better then 15 centimetres. As the light ray traverses the foliage of a tree it returns several reflections. Collecting the first, tree height, return will hopefully make it possible to correctly model the silhouette of forested islands.

Under water: In Sweden the National Hydrographical Office administers underwater data. The depth databases are classified but chart data is available. Chart data are generalized data from the depth database. The data sets are of different quality. In the commercial tracks the reliability is very high, but along the long Swedish coast there are large areas with old soundings of varying quality. For the pleasure crafts it is a particular problem that very little effort is put into soundings on shallow waters (depths less than 3 meters). Helicopter carried laser bathymetry, which with two colour lasers that can measure the shallow areas of the archipelago will maybe be a solution but is still somewhat in the future.

6.0   NO GO AREA VISUALIZATION

How do we display depth information in a 3D-modell? One of the problems with traditional charts, particularly as the time allowed to read them is shortening as the speed is increasing, is the cognitive effort to calculate if there is enough water for the vessel. This calculation involves the own ship's draught, the tidal level and the depth on different places during the track as well as a consciousness of the chart datum.

The International Hydrographic Organization's (IHO) standard for electronic charts (ECDIS) allows for provisions making it possible to enhance a certain depth curve (of the one present in the chart, i.e. 3, 6, 10, 15 meters etc.) to make it possible to more rapidly recognise no go areas.

The obvious solution in a 3D-modell would be to once and for all solve the problem with the opacity of the sea, which hides the dangerous rocks from human sight.

Tests showed that this only created another unfamiliar environment. "Flying" over the underwater terrain made it difficult to judge the vertical position in the de facto two-dimensional environment of the display. Keeping the water surface in the 3D-modell not only constrained the vertical position of the camera, when in ship-position, but was also fundamental for the recognition and comparison of the model with the real world.

Instead we used the underwater mesh to generate No Go Area warning polygons, which are placed on the surface of the water and displaying waters to shallow for the vessel thus relieving the OOW from the clutter of depth curves and sounding numbers on a traditional chart, while still retaining the familiar view of the archipelago and the water surface. (See fig. 1.)

These No Go Areas are dynamically updated based on the current tidal level, the current draught of the ship, the amplitude of the waves and the elevation of the terrain under the surface.

The warning areas are derived from the intersection of a cutting plane with the underwater terrain. The cutting plane is placed at distance d from the 0-plane (chart datum), so that

$$d = TL - DR - 0.5WA - SM,$$

where TL is the current tidal level, either computed locally based on tidal tables, or, better, received on-line from weather service corrected with deviations due to air pressure, wind and local geographic

conditions. *DR* is the current draught of the ship, data brought in from sensors on board in real time and thus taking into account not only the cargo weight but also the changing status of fuel and changes in draught due to the water density. *WA* is the wave amplitude, or actually the heave amplitude, a mean value collected from a sensor onboard. *SM* is a security margin that can be individually set and can depend on different factors as for example the quality of the soundings in the area. (See fig. 3.)
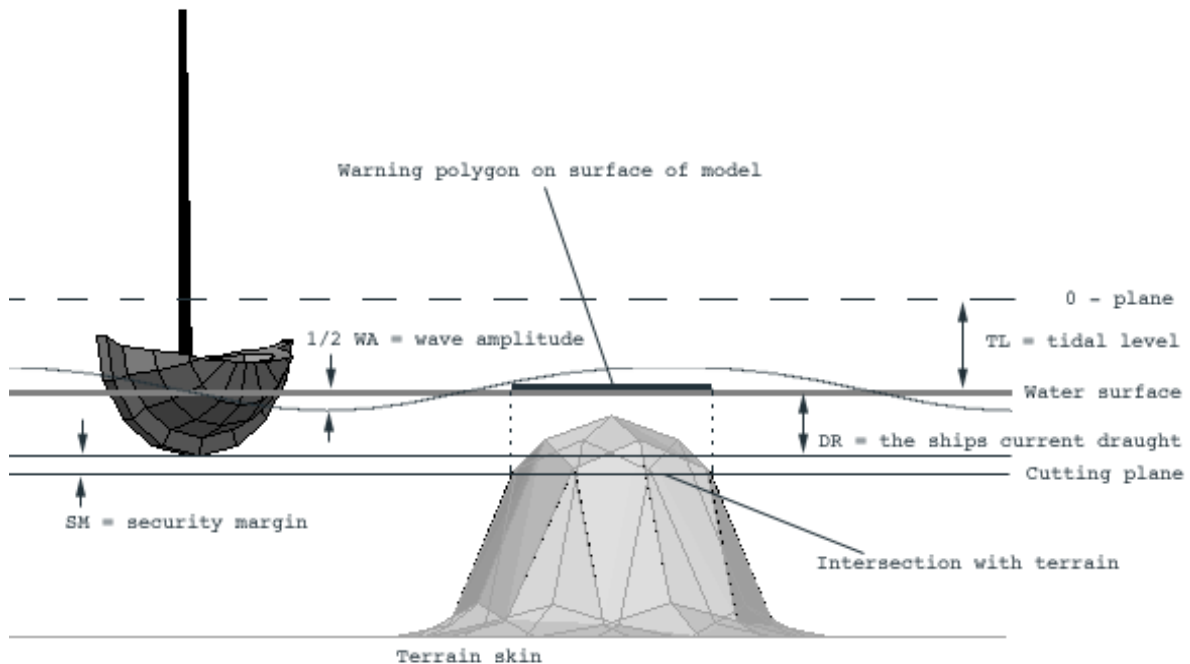

Figure 3: A Schematic Model Showing the Construction of the No Go Area Warning Polygons.

7.0   CONCLUSION AND FUTURE RESEARCH

The main focus of this research project is information design: how to display crucial navigational information to the OOW in an intuitive and reliable way. There is a lot of testing ahead to verify our suggestions.

Further items that remain to be dealt with, is the representation of radar echoes. Briefly put, the radar echo is used to check the positioning of the system and an echo not accounted for in the database is displayed as an unidentified object, represented by some geometric mean.

Vessels equipped with the Automatic Identification System (AIS) transponders send information to surrounding vessels containing the ships name, length, width, destination, cargo, course, speed and position, etc. This information can be used to tag radar echoes, or to place a tagged symbol in the electronic chart. In the proposed system a 3D-model of ships equipped with AIS-transponders in the vicinity can be inserted at the correct position. An amendment to the IHO standard of AIS, compelling ships to send a number of waypoints ahead on their track along with the transponder information, could make it possible to visualize an approaching ships intended track (and not only an extrapolation of the present course and speed, as is a normal function in electronic charts), as well as launch collision warnings in appropriate cases.

Bridge-eye perspective of 3D-terrain has been used in maritime academy simulators for years. The novelty of the suggested system is in the use of the simulation environment to present navigational information onboard the ship.

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SYMPOSIA DISCUSSION – PAPER NO: 4

Author Name: Mr. Thomas Porathe, Mälardalen University, Sweden

Question:
As the high-speed ferry becomes more like a cockpit, can we apply what has been learned in cockpits to nautical navigation visualisation systems?

Author Response:
Traditionally the bridge of a ship is pretty easy going. There is a need to change the culture and perception of the captains and the training of the "pilots", so that much of what has been learned in the cockpits can be applied to high-speed ferry bridges.

Real-Time 3D Nautical

Navigational Visualisation

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Problem

• Shorter and shorter time for decision making due to higher and higher speeds of vessels and more and more instruments to watch.

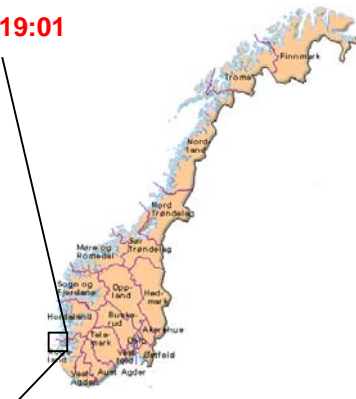High Speed Craft (HSC) "Sleipner" grounded on the 26th of Nov. 1999
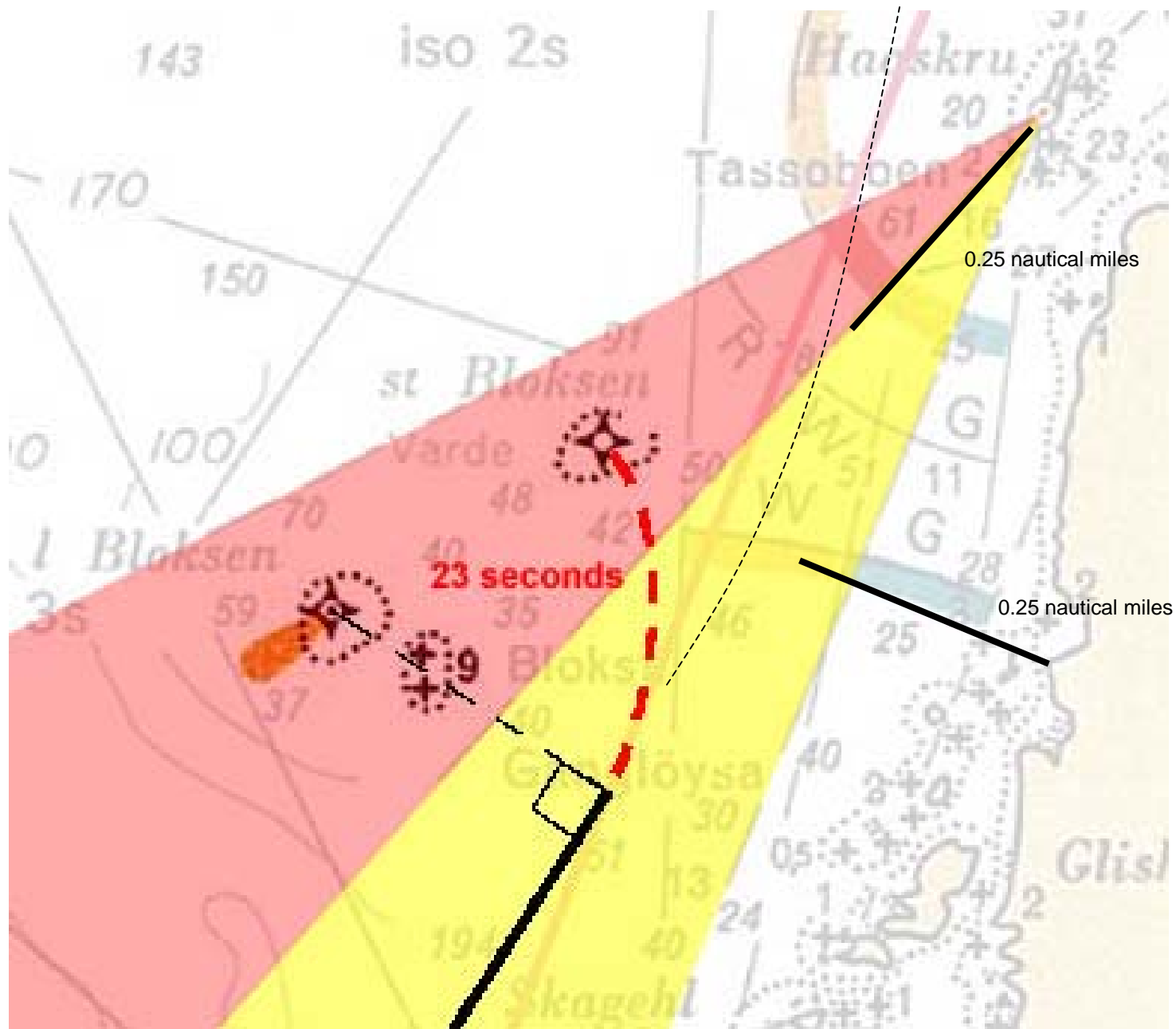
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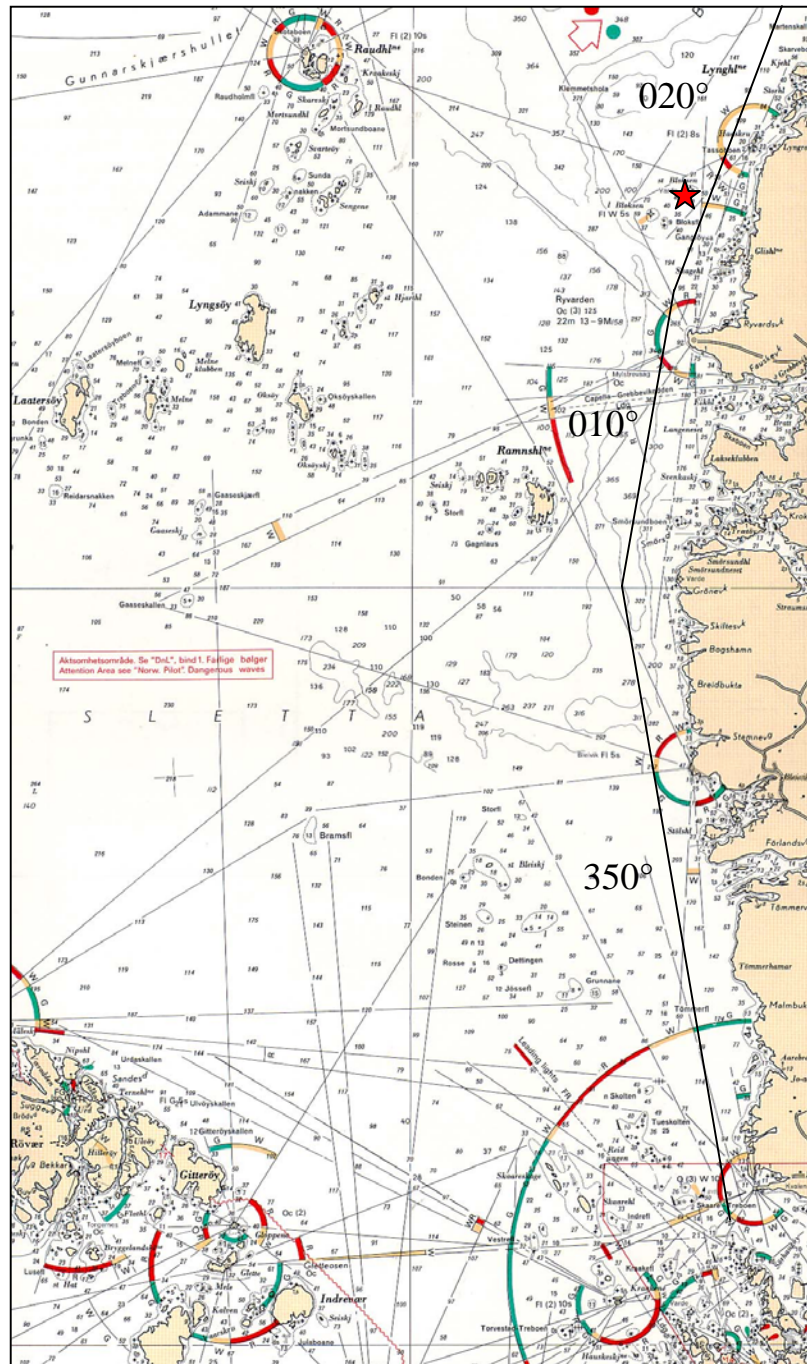
Grounded Big Bloksen 19:08

Ryvarden Light 19:06

010°

Bleivik Light 19:01

350°

Kvalen Light 18:53

Dep. Haugsund 18:47

4-4

120

141 Kjehl 56 2 + 1 27 35

Lynghl^{ne} 110 32

150 93 Storhl 52 11 22 +71

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hola 59 70 84 G 38 1 5 7

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Ganglöysa 40 Glishl^{ne}

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19:06 268 346 75 Fauskev^k Grebbevikodden Hamni Mölstrev

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apella—Grebbevikodden 180 33 9 0

Ldg 362 Eikhl 25 15 0 3

Avlöypet 16

0.25 nautical miles

0.25 nautical miles

23 seconds

Figur 6.1 Bilde av Store Bloksen sett mot øst[68]

Figur 6.4 Vraket av MS Sleipner, sett fra styrbord[73]

HSC 'Baronen' hits a rock south of Bergen in Norway on the 5th of Jan. 2000

"The captain of 'Baronen' was navigating on radar only when he hit the rock.
[- - -] The electronic chart was not used to establish exact position because the
capten meant that it would disrupt the concentration even more."

Bergen Avisen, 14th of Jan. 2000

246 out of 410 accidents in Hong Kong waters 1999 was collisions of some kind

"One notion that was put forward was that the bridges should only be equiped
with the instruments absolutly necessary. On a basic level the captain is relying
on visual information for decision making. When one adds watching a radar
screen it will take a little longer time to make the same decision. Adding jet
another screen, for example an electronic chart, it will take even longer."

From a field study of HSC ferry traffic in Hong Kong. Conclusions from interviewing
seven HSC officers made by Eva Olsson, Man-Machine Interaction, Dep. of Information
Technology, University of Uppsala, Sweden

Is it fair to say that navigation tools like

   - Radars
   - Charts
   - Compasses

take an effort to translate into visualisation
and therefore are not used in all situations where they
should have been used?
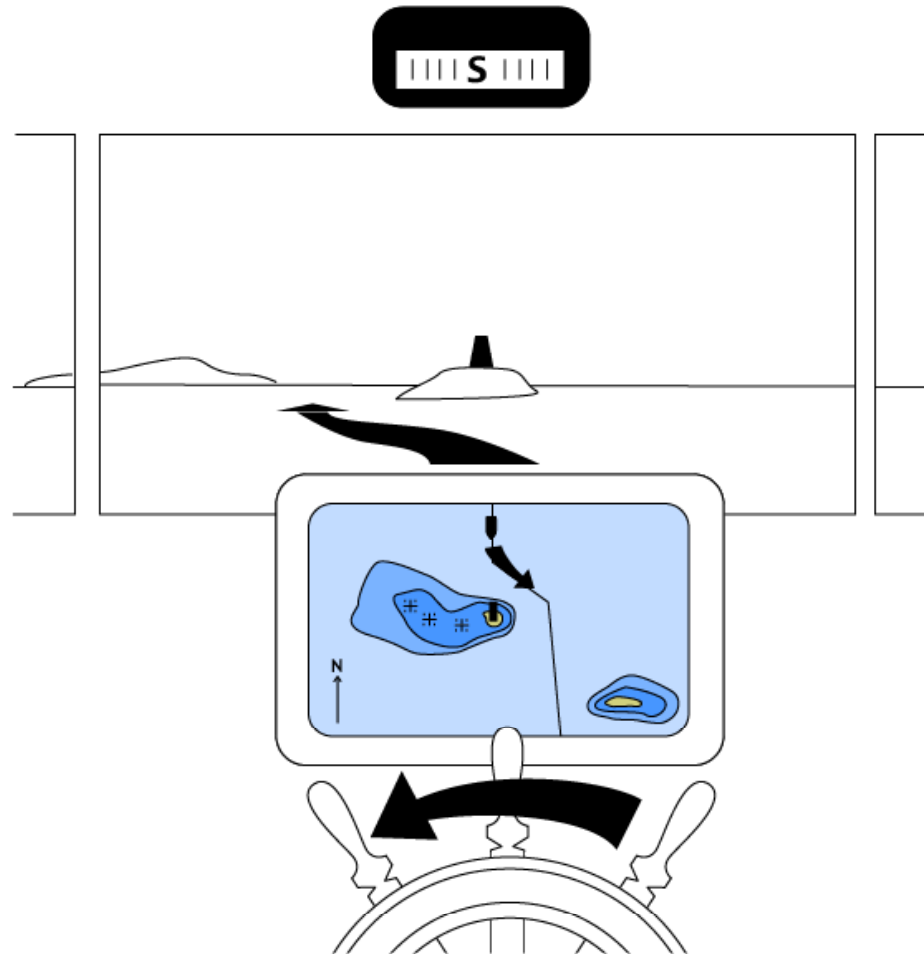
**The effort takes time.**

Time is what we are running short of.
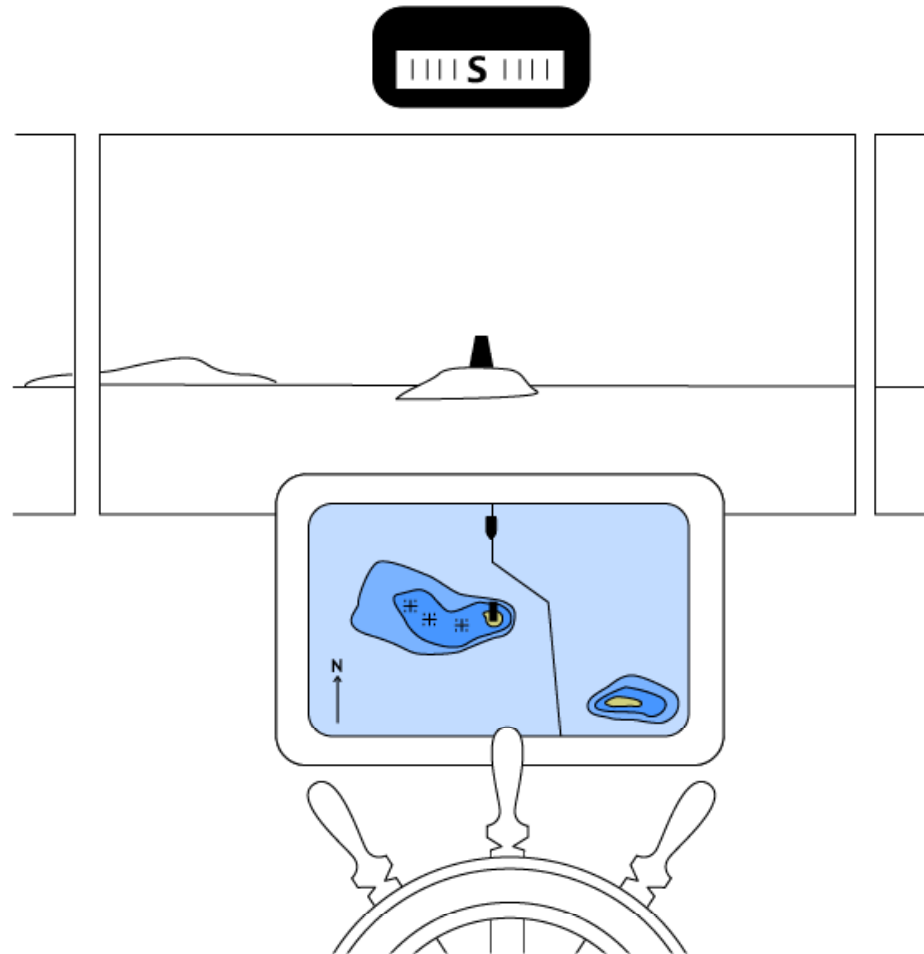
The cognitive problem of directions on southbound courses with charts and radar displays in a north-up mode.
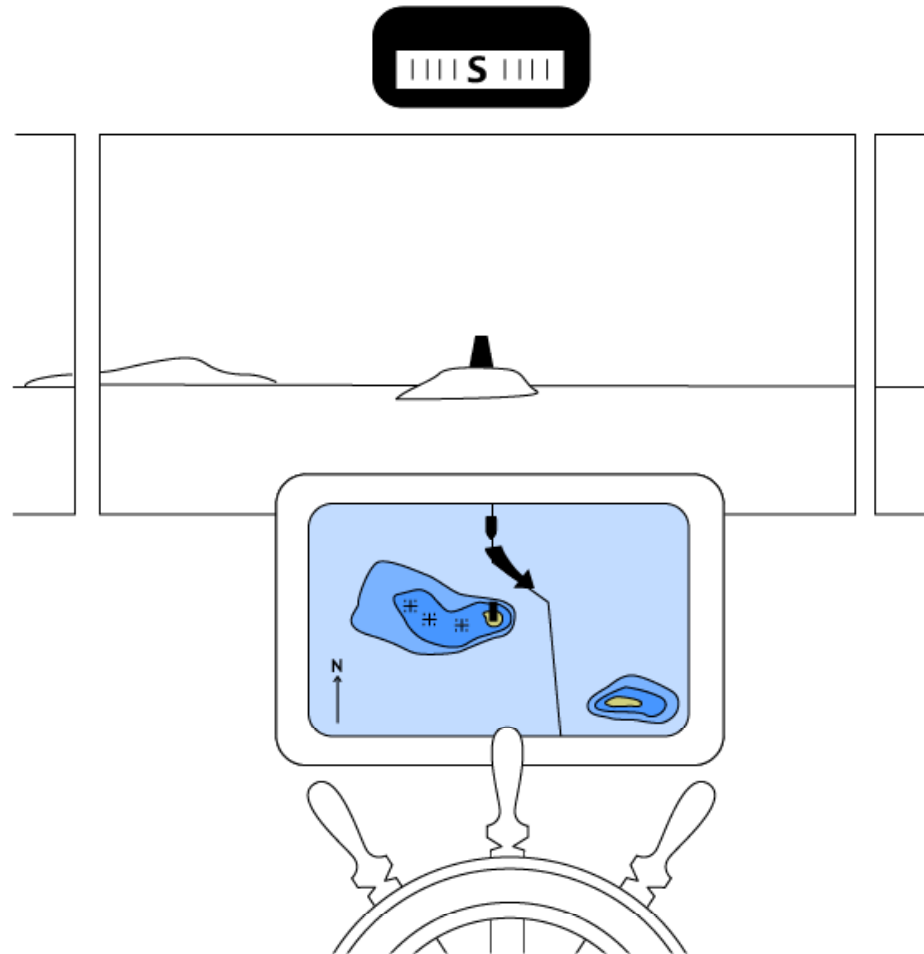
The cognitive problem of directions on southbound courses with charts and radar displays in a north-up mode.

The cognitive problem of directions on southbound courses with charts and radar displays in a north-up mode.
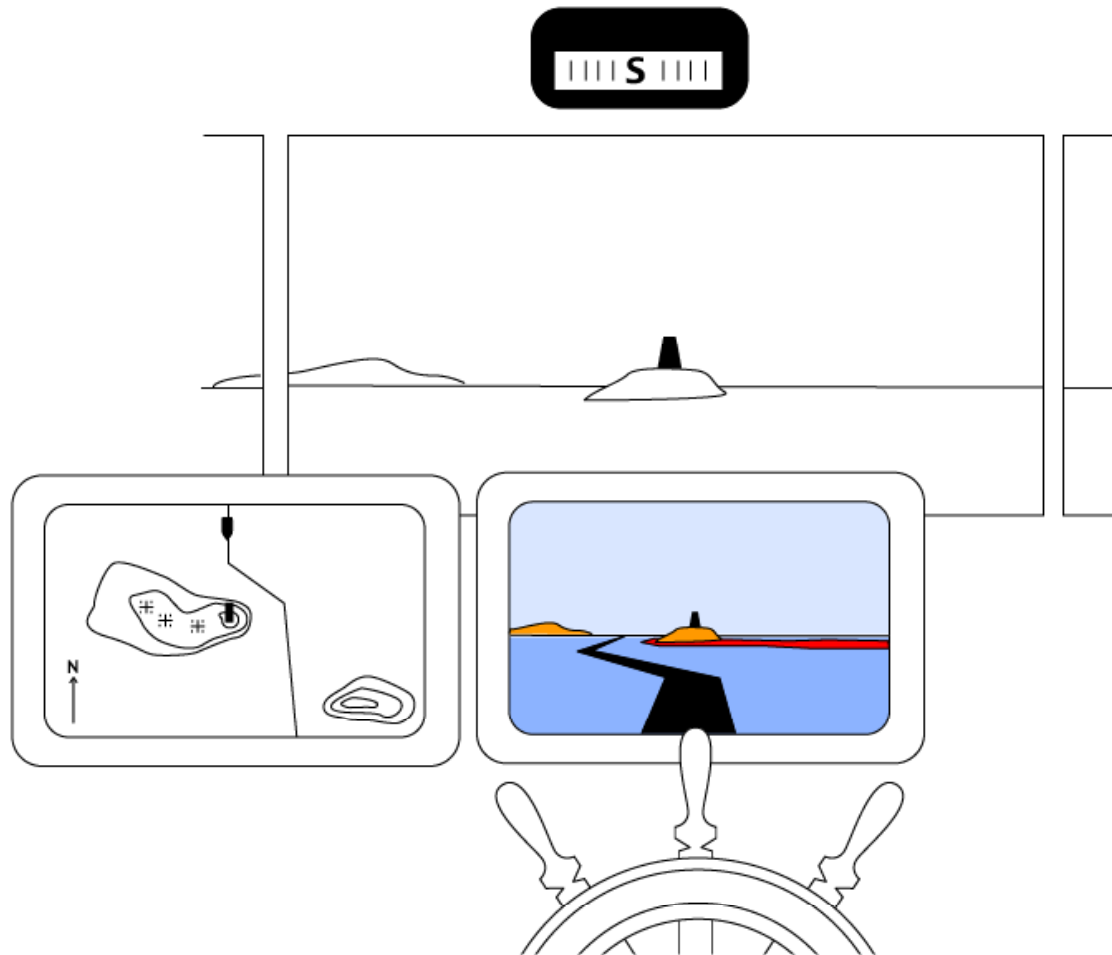
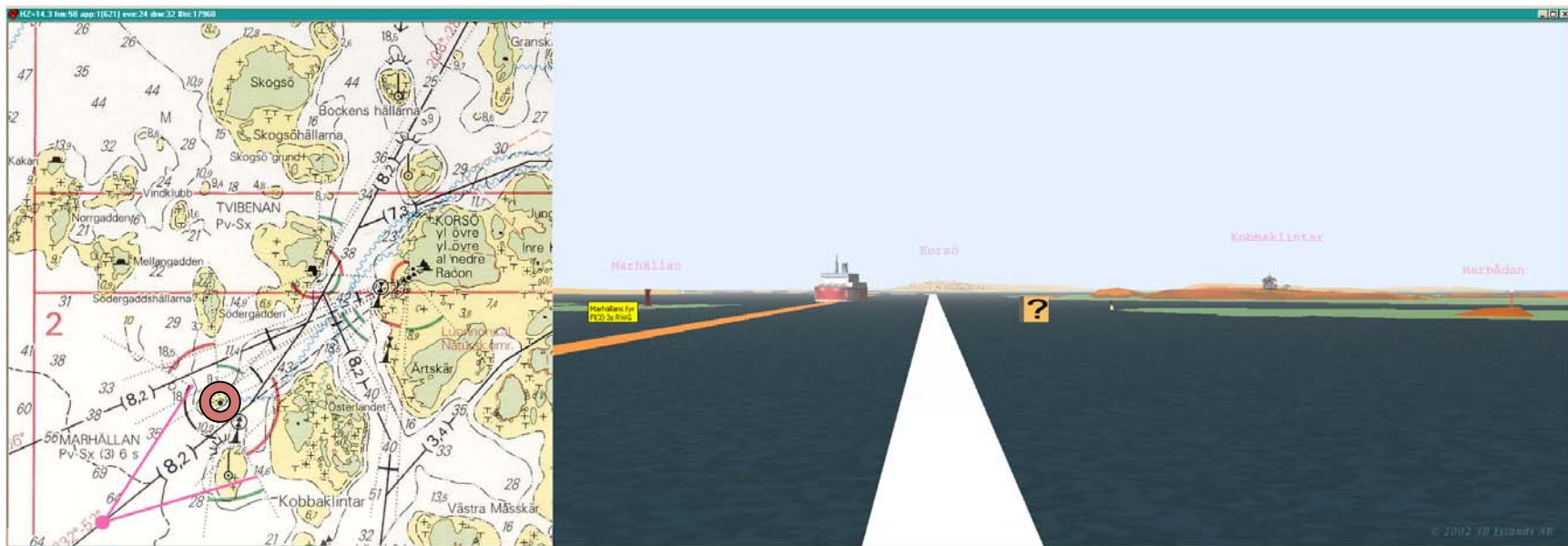A 3D-chart with a display in a bridge-view perspective solves the directional problem.
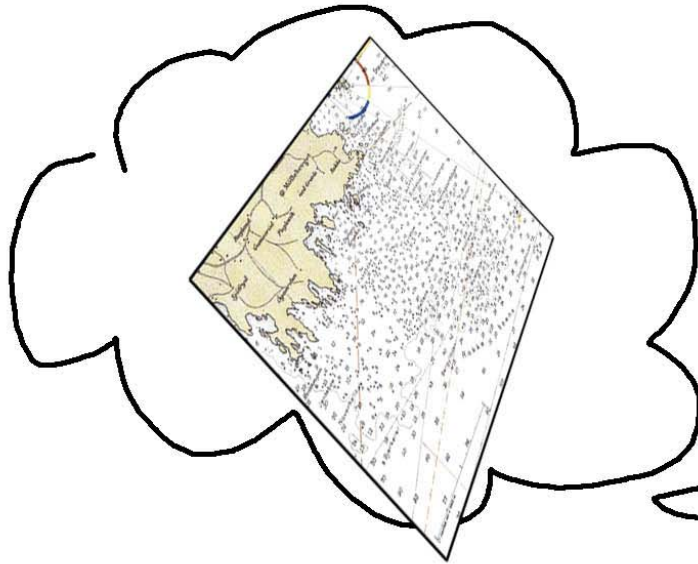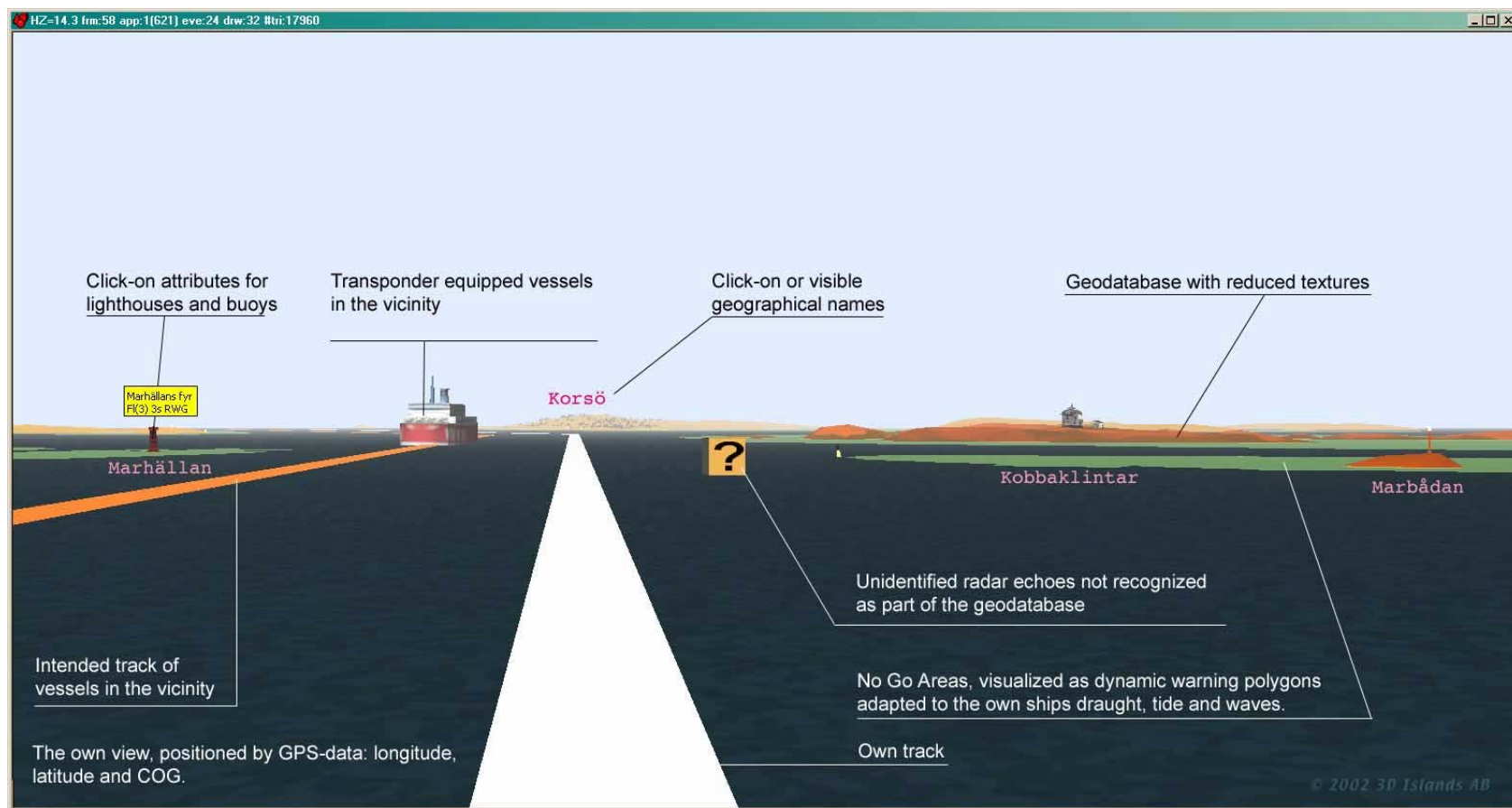
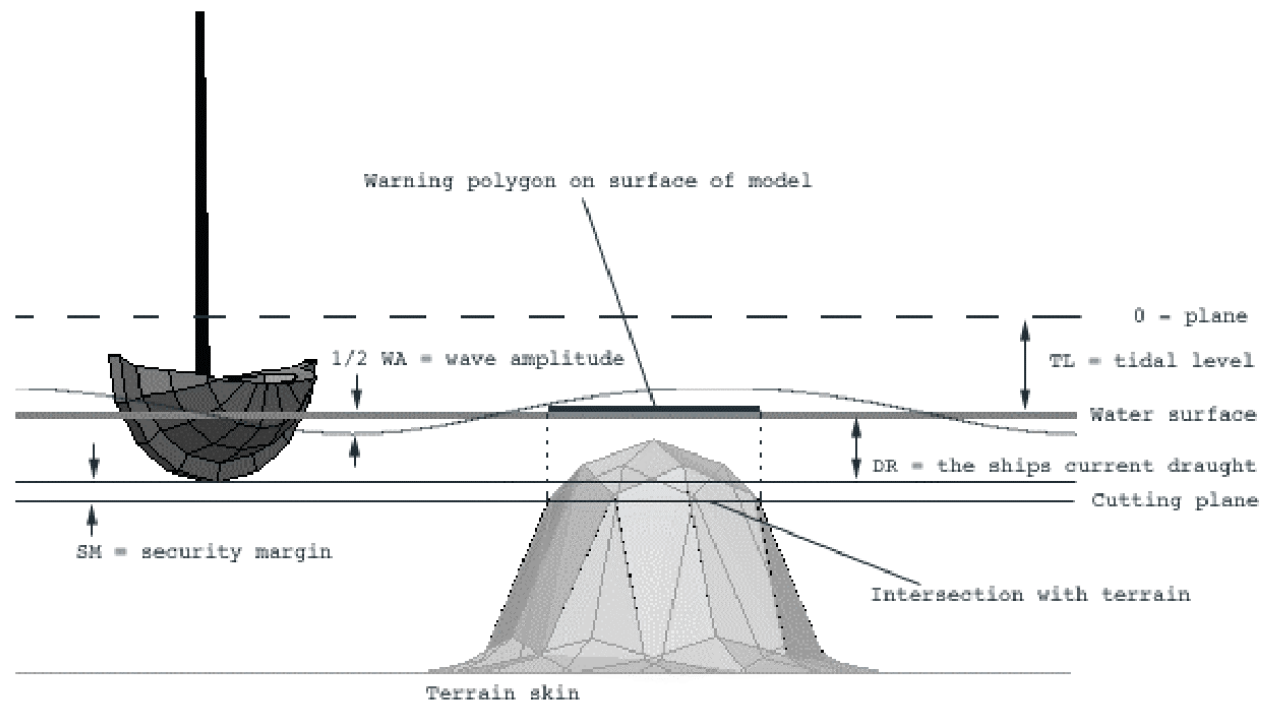Cognitive maps
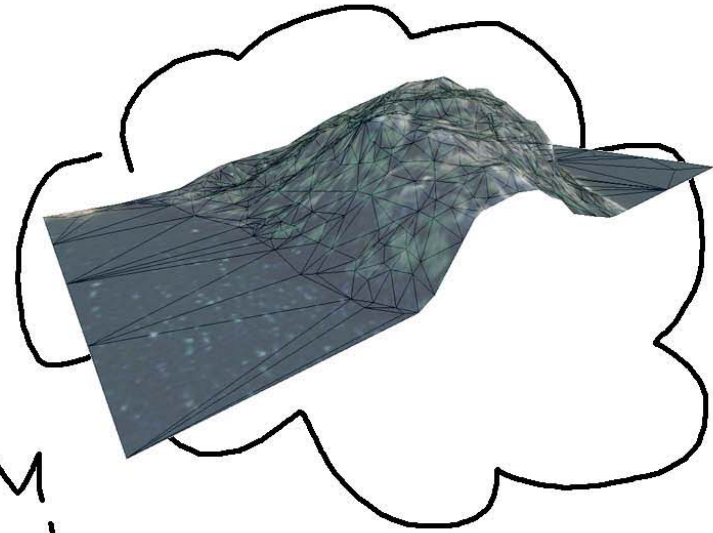
Spatial Mental Models

Barbara Tversky, 1993

A screen dump from 3D-chart connected to a electronic raster chart. Entrance to the Åland archipelago in the Baltic sea. Position and view direction marked in the raster chart. A click on Marhällan light reveals attributes as well as high lights it position in the raster chart.
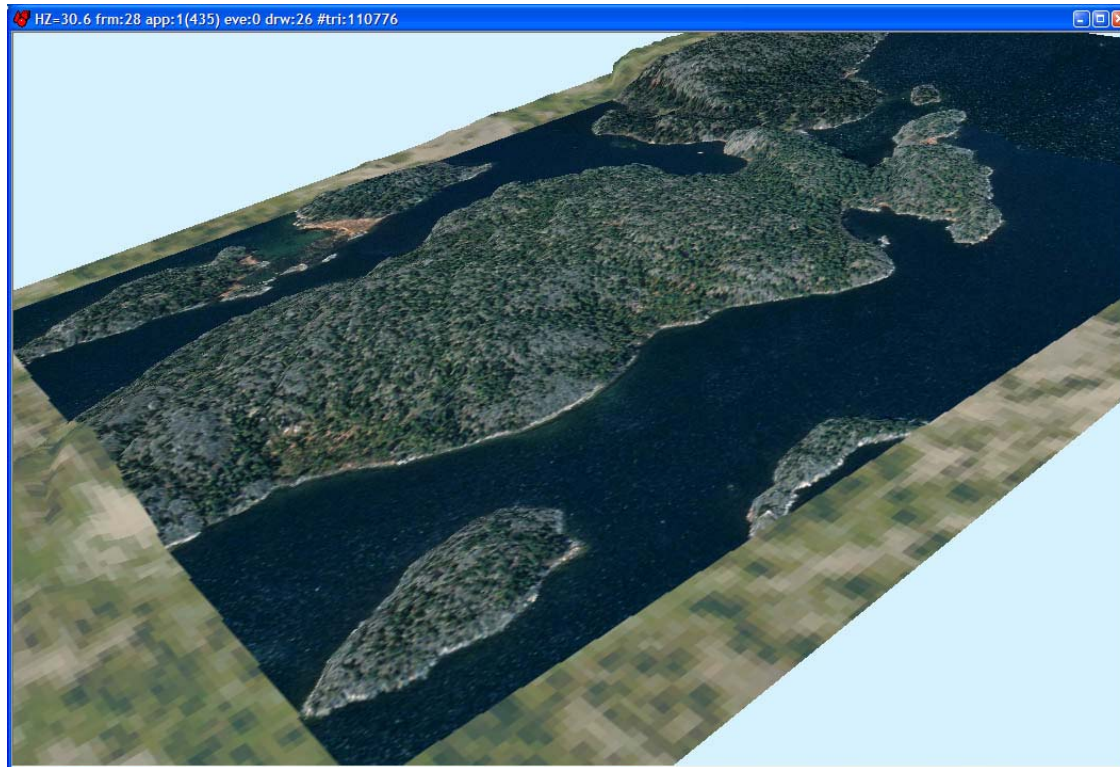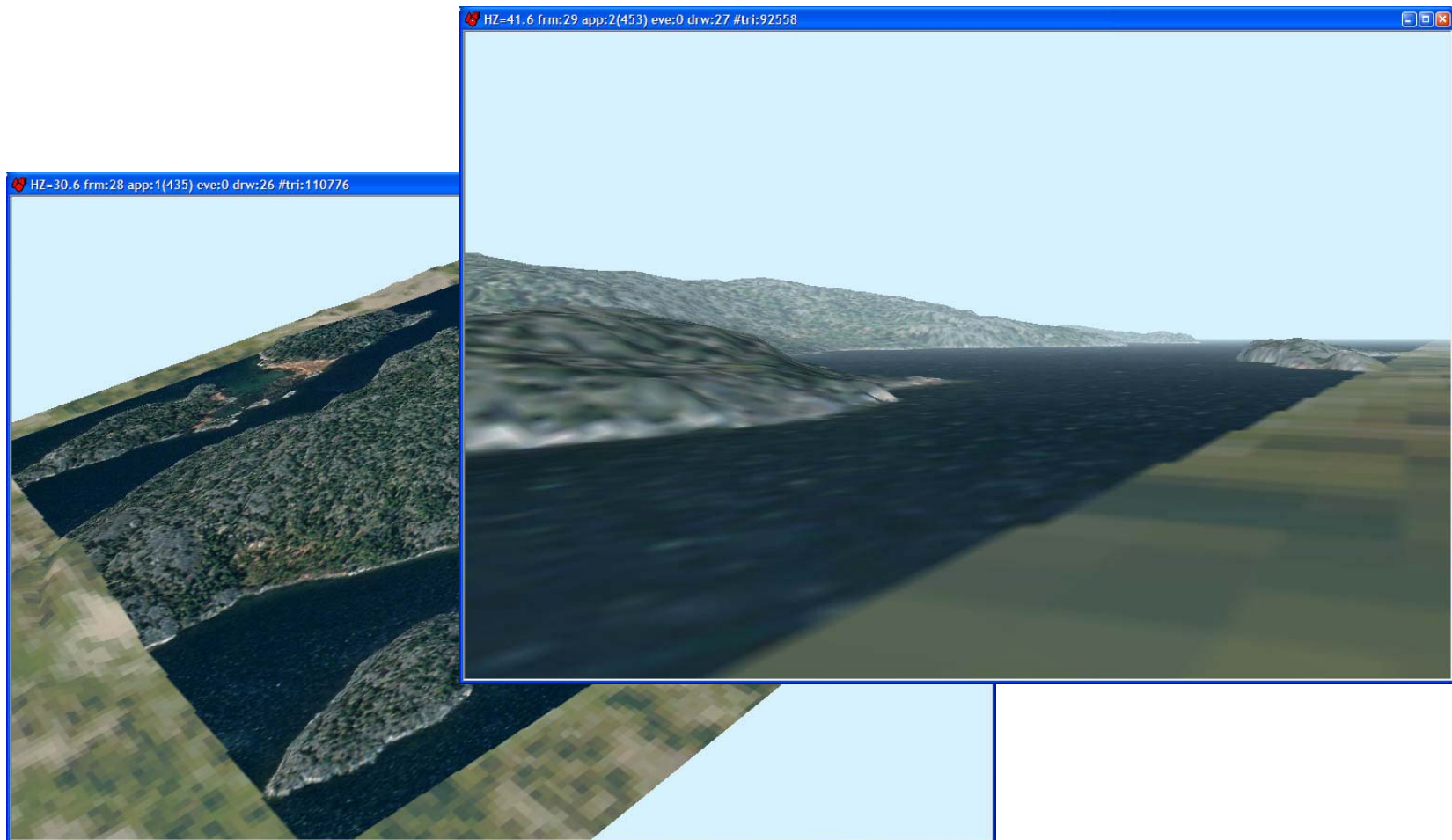

Features of the 3D-chart. Åland archipelago.

Real-time 3D demonstrator

Start	Stop

Warning polygon on surface of model

0 - plane

1/2 WA = wave amplitude

TL = tidal level

Water surface

DR = the ships current draught

Cutting plane

SM = security margin

Intersection with terrain

Terrain skin

Conclution

On going work: tree visualisation, getting the right silhouette on forested islands.

Next step: get a working prototype in a HSC

The big question: Will it be used?